SIMULTANEOUS SPECTRAL AND TIMING OBSERVATIONS OF ACCRETING NEUTRON STARS

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Final Report

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All six Rossi Timing Explorer (RXTE) observations approved for this proposal were carried out. Four of the observations were simultaneous with BeppoSAX (two of the source 4U1820-30, and one each of 4U1636-536 and 4U0614+091) and two were simultaneous with ASCA (of 4U1636-536 and of 4U0614+091). RXTE experienced a single event upset and went into a safe hold mode during the first 4U0614+091 observation and remained in safe hold until after the scheduled start of the second 4U0614+091 observation. An additional observation of 4U0614+091 was performed with RXTE to make up for the lost time. However, it was not possible to arrange for simultaneous observations with either BeppoSAX or ASCA.

Our work has led to three papers directly related to observations made - one paper for each source observed - and one additional paper summarizing our progress in this field. In addition, several reports on these results were made at various conferences.

In "Discovery of Microsecond Soft Lags in the X-Ray Emission of the Atoll Source 4U1636-536", by P. Kaaret, S. Piraino, E.C. Ford, and A. Santangelo, published in the Astrophysical Journal Letters, we presented the first measurement of microsecond timing lags from the neutron-star x-ray binary 4U1636-536. Our results showed that the hard x-ray emission precedes the soft x-ray emission. We also analyzed archival data from 4U1608-52 and showed that the sign and magnitude of the lags in that source are very similar to those seen in 4U1636-536. Our results corrected a sign error in previously reported measurements of microsecond lags in 4U1608-52. The correction of this error eliminates the most commonly used model for generation of these lags, Compton up-scattering of cool photons injected into a hot medium.

In "Strong Field Gravity and X-Ray Observations of 4U1820-30", by P. Kaaret, S. Piraino, P.F. Bloser, E. C. Ford, J.E. Grindlay, A. Santangelo, A.P. Smale, and W. Zhang, published in the Astrophysical Journal Letters, we report our analysis of correlations between the kilohertz quasiperiodic oscillations (QPOs) and the spectral state of the neutron-star x-ray binary 4U1820-30. We show that the QPO frequency is well correlated with x-ray color, but not well correlated with x-ray counting rate or x-ray flux. Most importantly, we show that the QPO frequency saturates at high inferred mass accretion rates. We interpret this as evidence for the existence of the marginally stable orbit, a key prediction of strong-field general relativity.

In "BeppoSAX Observations of the Atoll X-Ray Binary 4U0614+091", by S. Piraino, A. Santangelo, E.C. Ford, and P. Kaaret, published in Astronomy and Astrophysics Letters, we report on a highly accurate measurement of the broad band (0.3-150 keV) x-ray spectrum of the neutron-star x-ray binary 4U0614+091. This paper is derived from observations obtained under this proposal. However, the results are scientifically more applicable to the proposal NASA NAG5-7477, "Hard X-Ray Emission of X-Ray Bursters", PI: Philip Kaaret, and we describe them in the final report for that proposal.

Our x-ray timing results from RXTE on 4U0614+091 are described in "Spectral Signatures of KiloHertz Quasi-Periodic Oscillations from Accreting Neutron Stars", by P. Kaaret, which has been submitted to Astrophysical Letters and Communications. This paper also

contains additional material on our results on 4U1820-30 concerning the marginally stable orbit.

Posters/Talks -

"Strong-Field Gravity and RXTE/BeppoSAX Observations of 4U1820-30", by S. Piraino, E.C. Ford, A. Santangelo, and P. Kaaret was presented at the 19th Texas Symposium on Relativistic Astrophysics and Cosmology held in Paris during December 1998.

"Strong-Field Gravity and RXTE/BeppoSAX Observations of 4U1820-30", by S. Piraino, E.C. Ford, A. Santangelo, and P. Kaaret was presented at the 193rd meeting of the American Astronomical Society in Austin, Texas, January 1999.

"Joint RXTE-BeppoSAX/ASCA Observations of the Atoll X-Ray Binary 4U0614+091: Correlation between Fast QPOs and Spectral Shape", by S. Piraino, P. Kaaret, A. Santangelo, and E.C. Ford was presented at the American Astronomical Society, HEAD meeting, April 1999.

"KiloHertz QPOs and the Marginally Stable Orbit", by P. Kaaret was presented at the American Astronomical Society, HEAD meeting, April 1999.

"BeppoSAX Observations of the Atoll X-Ray Binary 4U0614+091", by S. Piraino, P. Kaaret, A. Santangelo, and E.C. Ford was presented at the NATO Advanced Study Institute on "The Neutron-Star - Black Hole Connection", June 1999.

"Spectral Signatures of KiloHertz Quasi-Periodic Oscillations from Accreting Neutron Stars", by P. Kaaret, was invited talk at "X-ray '99: Stellar Endpoints, AGN and the Diffuse Background" held in Bologna, Italy, September 1999.

Papers -

"Discovery of Microsecond Soft Lags in the X-Ray Emission of the Atoll Source 4U1636-536", P. Kaaret, S. Piraino, E.C. Ford, and A. Santangelo, Astrophys. J. Letters 514, L31-L33 (1999).

"Strong Field Gravity and X-Ray Observations of 4U1820-30", P. Kaaret, S. Piraino, P.F. Bloser, E. C. Ford, J.E. Grindlay, A. Santangelo, A.P. Smale, and W. Zhang, Astrophys. J. Letters 520, L37-L40 (1999).

"BeppoSAX Observations of the Atoll X-Ray Binary 4U0614+091", S. Piraino, A. Santangelo, E.C. Ford, and P. Kaaret, Astronomy and Astrophys. Letters, 49, L77-L81 (1999).

"Spectral Signatures of KiloHertz Quasi-Periodic Oscillations from Accreting Neutron Stars", P. Kaaret, has been submitted to Astrophysical Letters and Communications.